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TOTAL ELECTRON CONTENT MODEL FROM INTASAT DATA.(U)
MAY 79 J O CARDUS, L F ALBERCA, E GALDON AFOSR-78-3498

UNCLASSIFIED SCIENTIFIC-7 AFGL-TR-79-0182 NL

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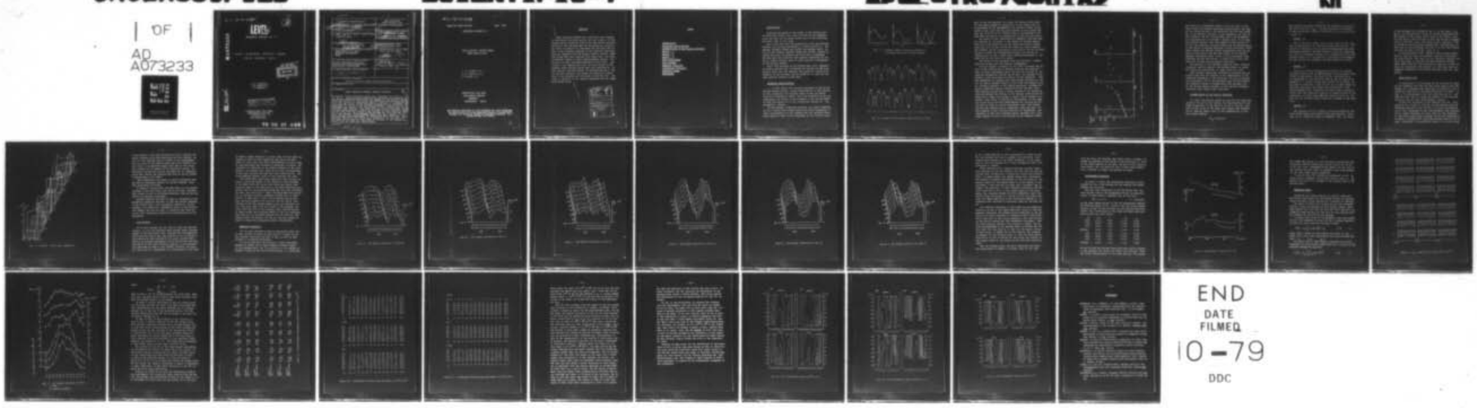

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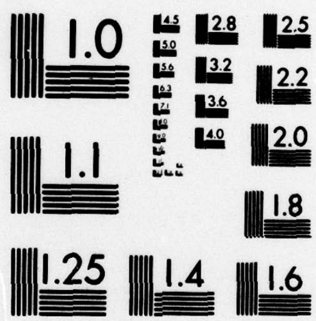

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SCIENTIFIC REPORT N° 7

AD A073233

TOTAL ELECTRON CONTENT MODEL FROM INTASAT DATA

J. O. Cardús S.I.
L. F. Alberca S.I.
E. Galdón S.I.

OBSERVATORIO DEL EBRO
IONOSPHERIC SECTION
ROQUETAS
(Tarragona) Spain

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REPORT DOCUMENTATION PAGE

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1. Report Number: 18 AFGL-TR-79-0182	2. Govt Accession No.
	3. Recipient's Catalog Number: 9
4. Title (and Subtitle): 6 TOTAL ELECTRON CONTENT MODEL FROM INTASAT DATA	5. Type of Report & Period Covered: FINAL [redacted] Report 1 Mar [redacted]78 — 28 Feb [redacted]79
	6. ~~Performing Org. Report Number~~
7. Author(s): 10 J. O. Cardús, s.I. L.F. Alberca, s.I. E. Galdón, s.I.	8. ~~Contract or Grant~~ Number: 15 AFOSR-78-3498 new
9. Performing Organization Name and Address: Observatorio del Ebro Roquetas (Tarragona) Spain	10. Program Element, Project, Task Area & Work Unit Numbers: 62101F 16 464305CE 17 Ø5
11. Controlling Office Name and Address: Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Monitor/John P. Mullen/PHP	12. Report Date: 11 3 May [redacted]979 12 37p
	13. Number of Pages: 32
14. Monitoring Agency Name and Address: 14 SCIENTIFIC-7	15.

16. & 17. Distribution Statement

Approved for public release; distribution unlimited.

18. Supplementary Notes

19. Key Words

Total electron content. Faraday rotation.

20. Abstract

Total electron content data (TEC) have been deduced, by the Faraday rotation method, from the signals of the spanis-h beacon satellite INTASAT for the period Feb.1975-Sept.1976. The starting date of the period was established after an analysis to determine the time when the effect of the residual spinning of the satellite was negligible as compared with the Faraday effect. Monthly mean TEC values have been obtained from these data for every latitudinal degree of their subionospheric points for six half an hour intervals centered at 0900, 0930 and 1000LT in the morning and 1930, 2000 and 2030 LT in the evening. These monthly values have been analyzed to obtain seasonal and latitudinal TEC variations, and a model has been deduced, that gives TEC values as a function of the latitude and the month of the year for the range of latitude of the. Iberian peninsula and the intervals stated above.

FORM 1473

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AFGL-TR-79-0182

GRANT Nº AFOSR 78-3498 3 May 1979

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J. O. Cardús, s.I.

L. F. Alberca, s.I.

E. Galdón, s.I.

OBSERVATORIO DEL EBRO

IONOSPHERIC SECTION

ROQUETAS

(TARRAGONA) Spain

THE RESEARCH REPORTED IN THIS DOCUMENT HAS BEEN SPONSORED IN PART BY THE AIR FORCE CAMBRIDGE RESEARCH LABORATORIES THROUGH THE EUROPEAN OFFICE OF AEROSPACE RESEARCH OAR UNITED STATES AIR FORCES.

A

ABSTRACT

Total electron content data (TEC) have been deduced, by the Faraday rotation method, from the signals of the spanish beacon satellite INTASAT for the period Feb.1975-Sept.1976. The starting date of the period was established after an analysis to determine the time when the effect of the residual spinning of the satellite was negligible as compared with the Faraday effect. Monthly mean TEC values have been obtained from these data for every latitudinal degree of their subionospheric points for six half an hour intervals centered at 0900, 0930 and 1000LT in the morning and 1930, 2000 and 2030LT in the evening. These monthly values have been analyzed to obtain seasonal and latitudinal TEC variations, and a model has been deduced, that gives TEC values as a function of the latitude and the month of the year for the range of latitude of the Iberian peninsula and the intervals stated above.

B

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C

INTRODUCTION

Polarization angles of the signal of the Spanish beacon satellite INTASAT have been recorded at the Obsservatorio del Ebro for the whole active life of the satellite, from Nov. 1974 to Oct. 1976.

Due to the fact that the satellite's orbit was sun-sincronous, the records correspond to a short period in the morning (between 0830LT and 1100LT) and another short period in the evening (between 1900LT and 2100LT). Before reducing the data, an analysis has been done to determine the time when the satellite was properly stabilized in order to obtain reliable data of total electron content(TEC) by the Faraday method.

About 1600 passages of the INTASAT have been analyzed to obtain seasonal and latitudinal TEC variations and a numerical model has been deduced, that gives TEC values as a function of the latitude and the month of the year for the time interval covered by the data.

SATELLITE STABILIZATION.

As is well known, the accurate obtention of TEC by the Faraday method requires a good stabilization of the satellite that eliminates its spinning about an axis different from tha transmitting dipole. When this condition is not accomplished, the Faraday effect appears in the records mixed up with variations due to the orientation changes of the transmitter antenna.

In the absence of Faraday rotation, the signal transmitted by a dipole that rotates about its center generating a cone, is received in a fix antenna with the strength variations shown in figs. 1a-1c, depending on the relative posi-

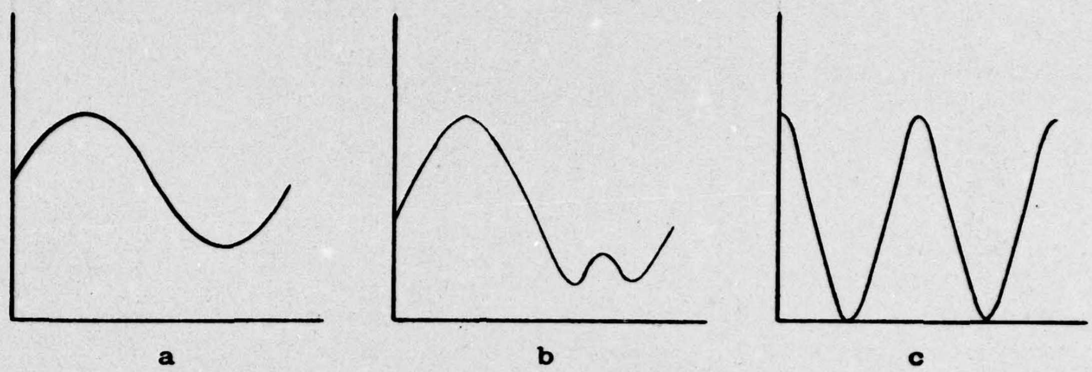

Fig. 1.- Strength signal variation produced by a rotating dipole on a fixed antenna

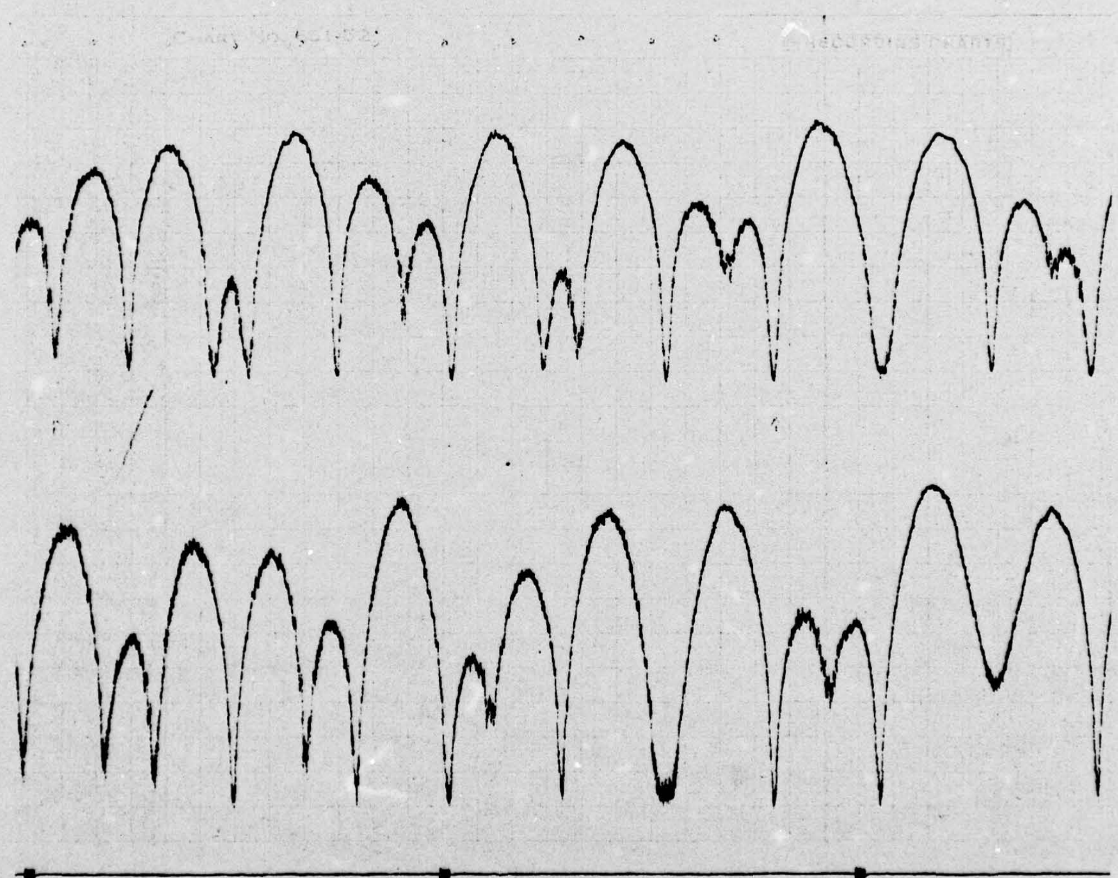

Fig. 2.- Record of the INTASAT orbit 120 (25-11-74)

tion of the two antennas (cf. Roger and Thomson 1960).When the receiving antenna is parallel to a line inside the cone generated by the transmitter, the received signal corresponds to fig. 1a if the receiving dipole is also inside the cone and to 1b if it is outside. Fig. 1c corresponds to the case when the dipole is perpendicular to the previous cases.

The effect of the interaction of satellite spin and Faraday rotation is two-fold: a) the number of fadings increases, and b) the variations on the receiving antenna change from fig. 1a-b to fig. 1c and the other way round, because the rotation of the polarization plane due to the TEC is equivalent to rotate the transmitting dipole. This effect is clearly seen in fig. 2 where the record corresponding to the orbit 120 of the INTASAT is shown.

The effect of the anomalous spin was gradually diminishing for several days and finally disappeared.

Several authors (Aitchison et al. 1959) discussed the effect of the interaction of Faraday rotation and satellite spin to deduce aproximate values of TEC from records of two separate frequencies (20 MHz and 40 MHz). We intended to determine a date from which the effect of the satellite spin was negligible as compared with the Faraday rotation in order to obtain accurate values of TEC. With this pupose we made a Fourier analysis of the signal amplitude, recorded for several satellite passes, between Nov.1974 and Feb. 1975. This analysis should give a period related to the satellite spin and another one related to the Faraday rotation.The Faraday effect shall not produce a unique period during a satellite pass, since it depends on the geometry of the magnetic field and on the TEC; nevertheless its spectrum is not too wide so that on certain conditions, both, the Faraday and the spin effects can be separated. Since the spin effect depends on the relative possition of transmitter and receiver, we have only analyzed nearly overhead, N-S (morning) orbits. In fig. 3 the periods of the analyzed orbits

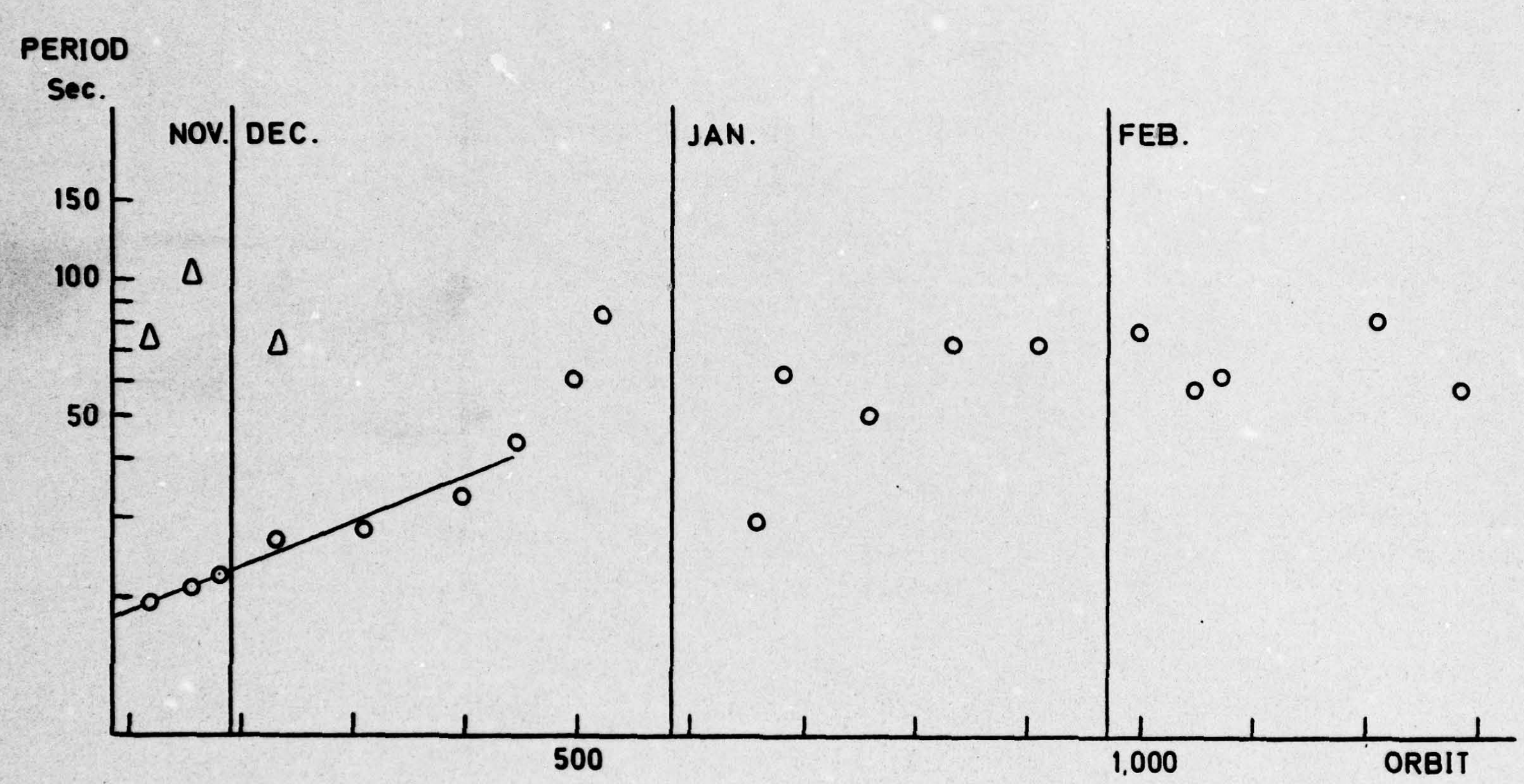

Fig. 3.- Main periods of the Fourier analysis for different orbits

are shown in a logarithmic scale. As can be seen, in the first orbits two clearly separated periods appear, the shorter one being related to the satellite spin and the longer one to the Faraday rotation. At the beginning, the spin effect prevails and the corresponding period is exponentially increasing.till it reaches a similar value to the Faraday rotation period. When this happens (about orbits 496 or 521) the frequency spectrum widens and the determination of the period of maximum amplitude is more difficult. After these orbits, the Faraday effect predominates over the satellite spin effect, and the main period of the Fourier analysis fluctuates about a more or less horizontal line, following the TEC variations. A linear fit was made till orbit 446 to show the exponential variation.

The results of this analysis indicates that, included a generous security margin, the Faraday method to obtain TEC values was applicable, at least, from Feb. 1975.

This analysis seems more accurate to determine the satellite spin than the measure of the temperatures in the different components of the satellite. In fact, according with Santullano (1975) the satellite spin did not produce any anomalous change of themperature from December 1st. In the Faraday angles records, on the contrary, irregular rotations still appear after this date.

DETERMINATION OF THE FARADAY ROTATION.

To obtain the Faraday angles we used the two close frequencies (40 and 41 MHz) method. The determination of the first coincidence of the nulls of 40 and 41 MHz has been done by one or two of the three more widely used methods; all of them are based, more or less inmediately, on the well known equation

$$\Omega_{41} = 19.75 \, \Delta\Omega$$

that relates the angle rotated by the polarization plane of the wave of 41 MHz(Ω_{41}) to the difference of rotation of the polarization planes of the wave of 40 MHz and 41 MHz ($\Delta\Omega$).

Method 1.

This is the most simple one. In some records with more than 10 nulls of 41 MHz, the point where the nulls of 40 and 41 MHz coincides, can be seen and determined with high probability.Besides, the null number 10 from the coincidence, that is recognized because of its equidistance from the adjacent nulls of 40 MHz,(cf.eq.1), can also be determined. If both results are coherent, the determination is valid.

Method 2.

From eq.1, values of Ω_{41} can be obtained for several successive nulls with the $\Delta\Omega$ measured in the records. From a null to the next one the value of Ω_{41} increases by π (or diminishes if the satellite goes to the N). Then,if we substract π (or add if the pass is S-N) to the value of Ω_{41} when we pass from a null to next one we shall obtain always the same value, the value that corresponds to the first analyzed null. In practice we often obtain different values with this procedure because of irregularities of the ionosphere. In these cases the mean value is given as the true one and the mean square error as a measure of the accuracy.

Method 3.

The validity of eq. 1 relies on the correctness of the first order theory from which it has been deduced. However, it is found very often in practice that the slope

of the straight line defined by eq. 1 in the plane (Ω_{41}, $\Delta\Omega$) is different from 19.75. To correct empirically for the absence of the higher order terms in the theory, Kersley and Taylor (1974) propose to find the best-fit straight line, of variable slope, for values of Ω_{41} measured from an arbitrary origin plotted against $\Delta\Omega$. Extrapolotion of this line to zero $\Delta\Omega$ gives the null of 41 MHz that coincides with the null of 40 MHz ($\Delta\Omega = 0$).

In our analysis we used Method 1 when possible; otherwise we used the other two methods, that very often gave the same results. When they did not, different external criteria were used to determine the most probable results. Among these criteria, the rejection of negative or null values, the comparison with results of a near pass or a too anomalous variation of TEC within the pass, were the most useful.

DATA CONSISTENCY.

An indication of the accuracy of the data can be obtained by comparing them with the TEC values deduced from the signals of a geostationary satellite. An example of such a comparison with data of the ATS-F satellite, is shown in fig. 4. It corresponds to TEC data from the 21st to the 24th Nov.1975. The TEC values are plotted at the latitude and local time of their subionospheric points.

We drew the variation of TEC obtained from the ATS-F satellite on a plane at 37ºN and the TEC deduced from the different passages of the INTASAT, in planes, perpendicular to this one, placed at the corresponding local time. There is a small variation of local time from the beginning to the end of each INTASAT passage but we have neglected it in order to simplify the figure. The dashed lines in the figure, correspond to extrapolated values. As it can be seen

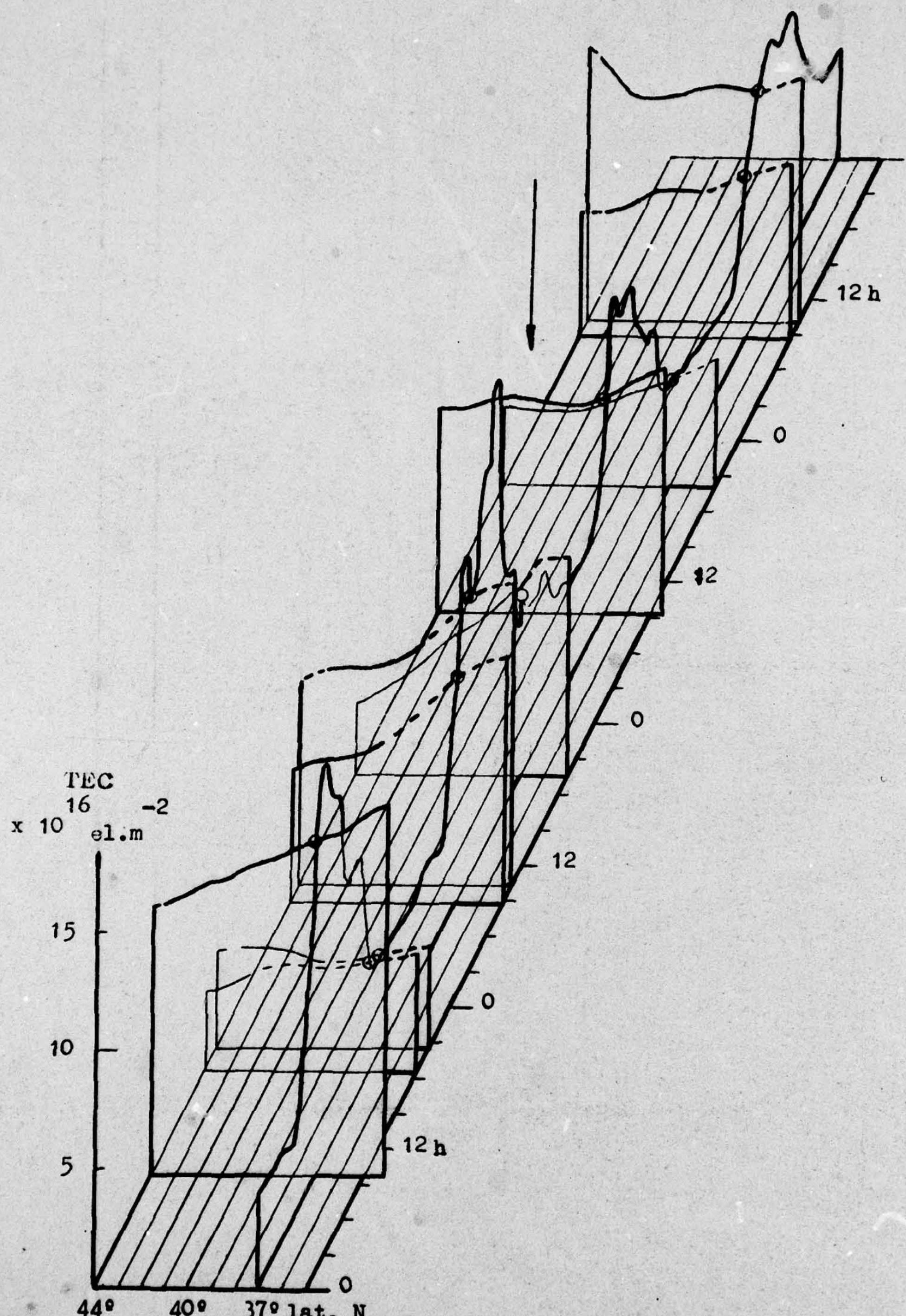

Fig. 4.- INTASAT - ATS/F data comparison

in the points of the same latitude and local time, the TEC values obtained from both satellites are very similar, except for one case: the pass at 1930LT on the 22nd, marked with an arrow in the figure, where the value deduced from the INTASAT is apreciably higher than that of the ATS-F. This anomaly can be caused by the relatively strong TEC variations during this period, probably due to a magnetic storm that started the previous day with an SSC at 2305UT, (corresponding to 23 30LT).

Other comparisons were made on several different days and similar agreement between the values obtained from both satellites was found.

It should be notted that although these are TEC values obtained at the same local time and at the same latitude, they belong in fact to different universal time and are obtained at different longitudes.

Another analysis was made in order to determine if the apparently anomalous variation of TEC for several passages of the INTASAT was a real ionospheric effect or, on the contrary, was caused by a systematic error of the calculation method. The results seem to indicate that they are in fact real variations produced by irregularities in the ionosphere.

DATA PROCESS.

As we have already said the INTASAT orbit was sun-sincronous, so that the satellite goes through every latitude always at the same local time. Although the subionospheric point does not follow the same pattern (as it is obvions), its position is also related to its local time. For this reason, an absolute separation of the latitudinal and diurnal effect on the total electron content, is not possible with the kind of orbit of the INTASAT. However, the diurnal effect can be diminished if a distribution of TEC data

is made in small intervals of local time. We have taken intervals of half an hour centered in the hours and half hours of local time. The data corresponding to each of these intervals,have been grouped by geographic latitude and longitude in intervals of one degree centered on the exact degrees. The monthly mean value of all data corresponding to the same latitude and hour has been considered as the representative monthly value of that latitude and time.

The restrictive space-time resolution that we have imposed, causes the number of TEC values at some latitudes to be small, with the result that there can appear some spurious peaks on the variation of TEC with different parameters, that do not correspond with the true mean variation. To avoid this difficulty a small smoothing has been performed in latitude through a weighted running mean of three values. In this way, a table of TEC monthly values have been obtained between 30ºN and 44ºN for the period Feb. 1975-Sept.1976 and corresponding to the six different local time hours 0900, 0930 and 1000LT in the morning and 1930, 2000 and 2030 in the evening. Since several values in these tables were missing, mainly in the low latitudes, they were cut to latitudes between 36º and 43ºN for the morning hours and between 38º and 43º for the evening in order to obtain and homogeneous space distribution.

SEASONAL VARIATION.

The TEC data obtained in the way described above, have been plotted as shown in figs. 5a-5f, in order to see the seasonal variation for each of the six half an hour periods, at different latitudes.

As can be seen from the figures, a clear consistent maximum in summer and a clear minimum in winter appear in the evening hours. The TEC variation in the morning is slightly different for the different hours. At 1000LT the

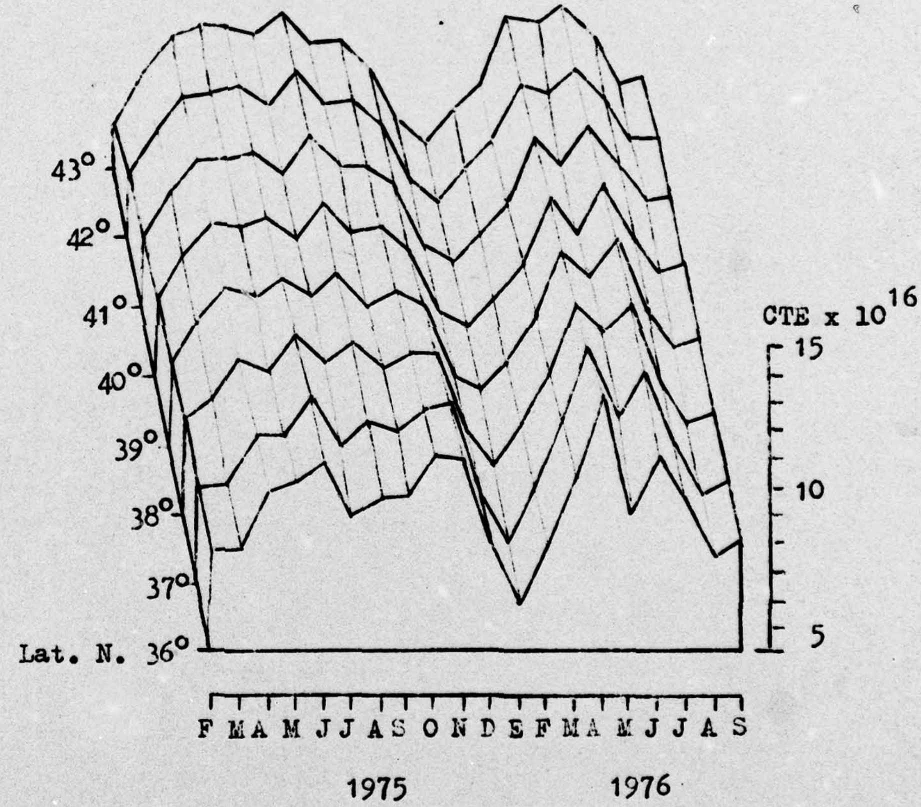

Fig.5 a .- TEC annual variation at 0900 LT

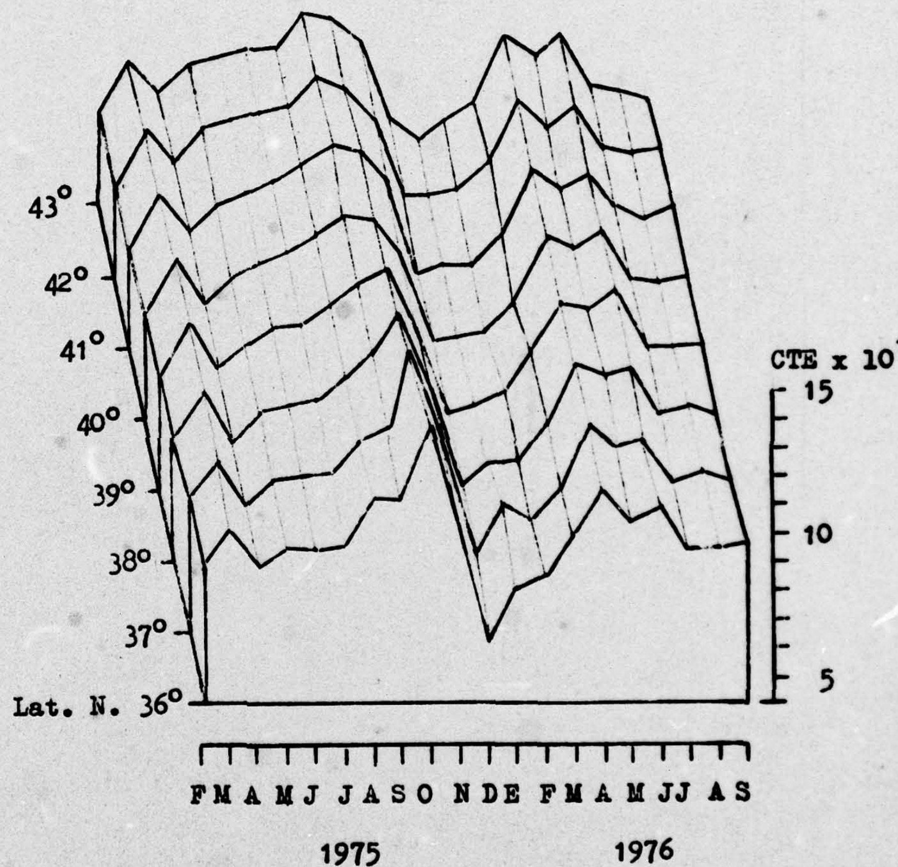

Fig.5b .- TEC annual variation at 0930 LT

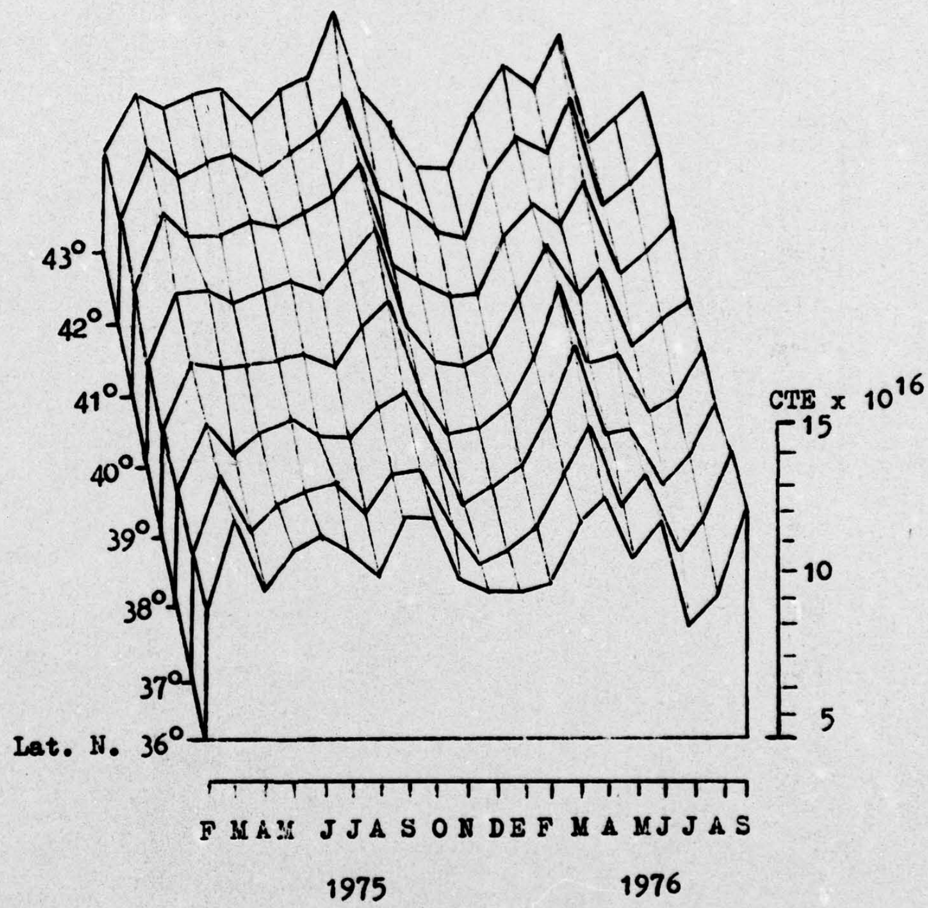

Fig.5 c .- TEC annual variation at 1000 LT

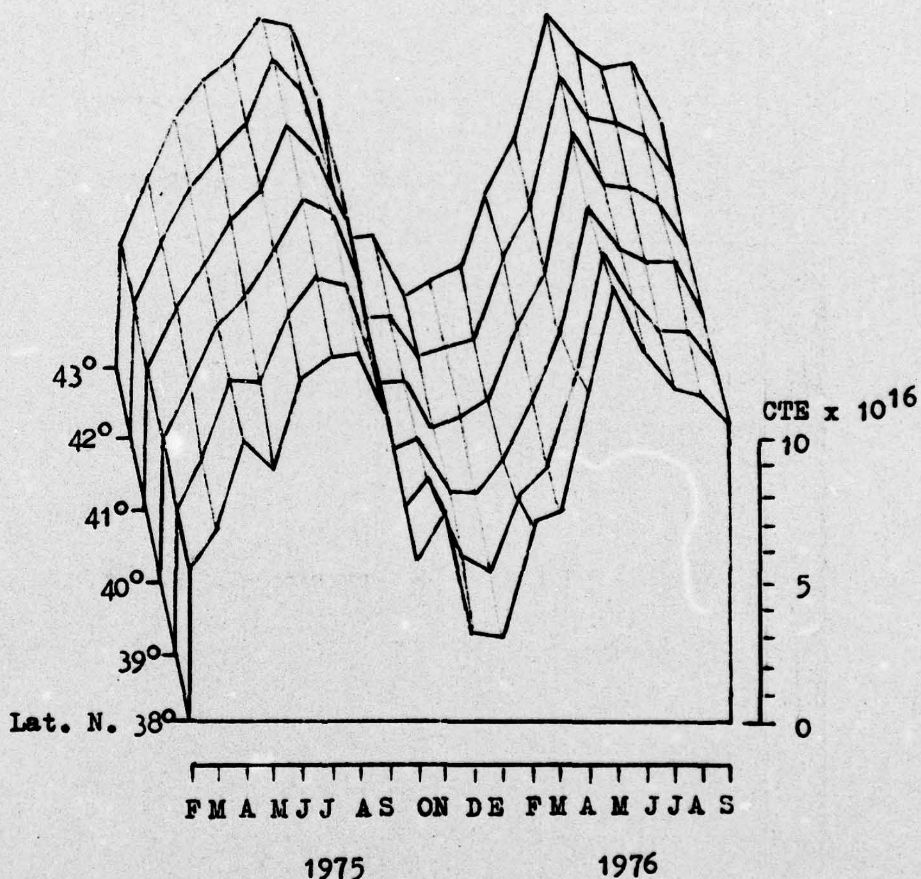

Fig.5 d .- TEC annual variation at 1930 LT

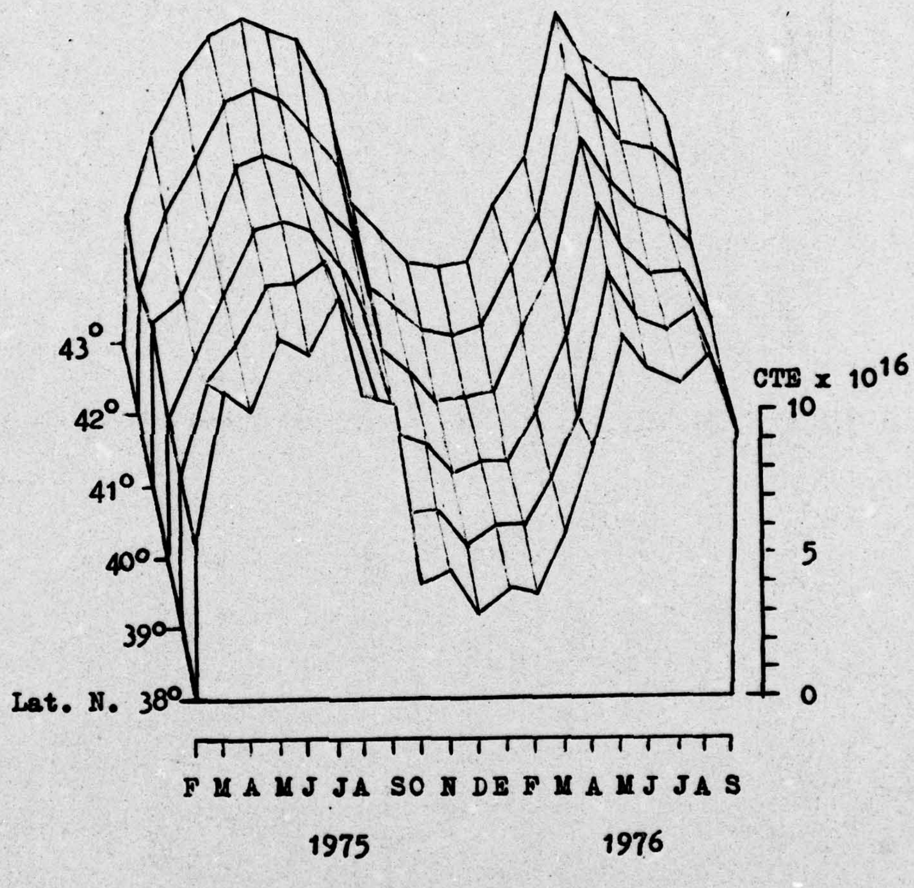

Fig.5 e .- TEC annual variation at 2000 LT

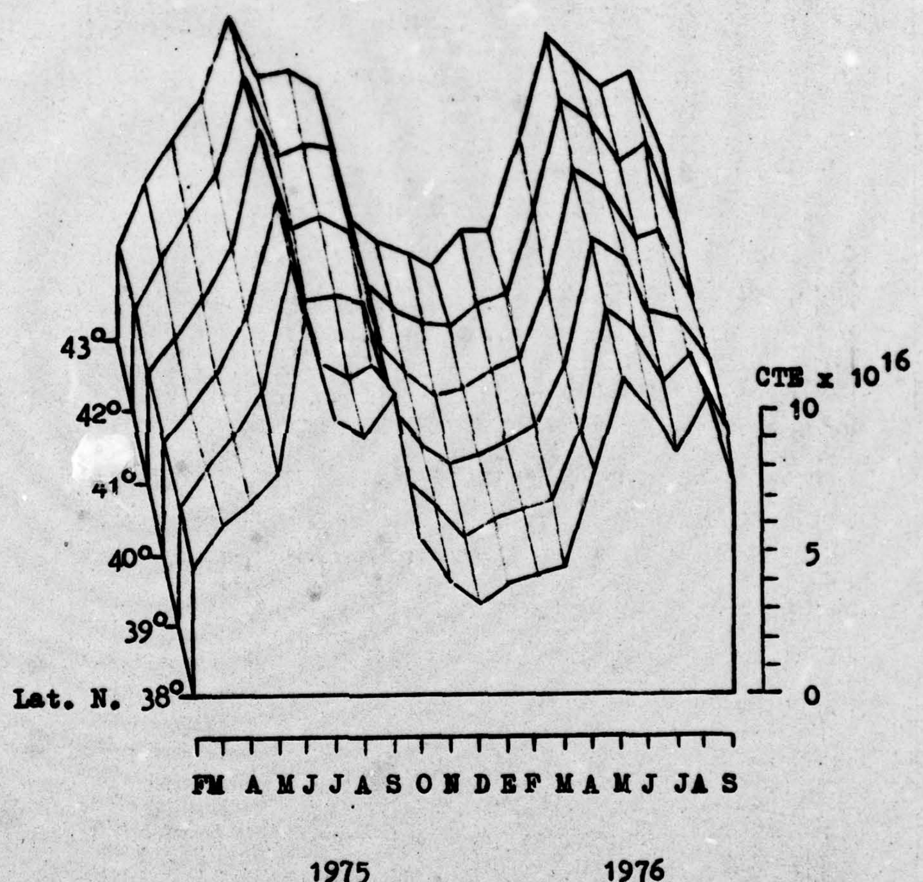

Fig.5 f .- TEC annual variation at 2030 LT

re is a double maximum at the equinoxes with minima in winter (the deepest one) and in summer. This variation that appears more clearly at the lower latitudes, is also apparent at 0930 LT although not so well defined,and still less distinctly at 0900LT.

These results can be compared with the seasonal variation obtained at the Observatorio del Ebro from the BE-B satellite data (Cardús,1966, Galdón,1970, Galdón and Alberca, 1971). In these papers only midday values were considered. The seasonal variation was similar to the one found in the present paper for the morning hours i.e.:two maxima at the equinoxes, a main minimum in winter and a secondary one in summer. The amplitude of this variation increases with the solar activity so that, at the lowest region of the solar cycle, the equinoxes maxima are only insinuated. Since the INTASAT data correspond to a period of very low solar activity, the small amplitude of the equinoctial maxima is in agreement with the kind of variation found for the BE-B data.

The different variation of TEC found for the different hours can be due to the daily variation, mixed up with the seasonal variation. The morning hours correspond to the period of the rapid increase of ionization after sunrise.The TEC at any time of this period depends on the time distance to the sunrise moment,and this dependence diminishes when the time distance increase. From winter to summer, the period corresponding to the morning hours is further and further away from the sunrise, so that the TEC should increase from winter to summer due to this effect. The increase is greater for the carlier hours. At 1000 the daily variation effect is not so strong and the curves are similar to the curves found for the midday period with BE-B satellite data.

For the evening hours, the daily variation also changes from winter to summer. In winter, they are far away

from the daily TEC maximum, that takes place at midday. In summer the maximum occurs latter in the afternoon so that in the hourly period of the data, the TEC is still high at this season. The TEC variation due to this effect should have a maximum in summer and minimum in winter.

LATITUDINAL VARIATION.

In order to obtain the latitudinal variation we have plotted in fig. 6 the morning and the evening TEC values between 30º and 44ºN.

The full dots correspond to all TEC values and the open circles only to the homogenized values as described above. We have fitted a straight line of the form

$$TEC = a_0 + a_1 \lambda \qquad (\lambda = \text{latitude})$$

by the least square method to the TEC homogenized morning and evening values of fig. 6 and to the TEC values corresponding to each of the six half an hour periods mentioned before. The coefficients of the lines and their most probable errors are given below:

LT	ao	e	a_1	e
0900	16.51	0.28	- 0.20	0.007
0930	16.33	0.10	- 0.18	0.003
1000	16.62	0.23	- 0.17	0.006
morning	16.45	0.07	- 0.18	0.002
1930	18.76	0.67	- 0.25	0.017
2000	18.84	1.33	- 0.27	0.033
2030	11.48	0.94	- 0.11	0.023
evening	16.39	0.97	- 0.21	0.024

As can be seen the morning hours have very similar values. At the evening, the values for 2030LT are different from the values corresponding to the other periods. The errors

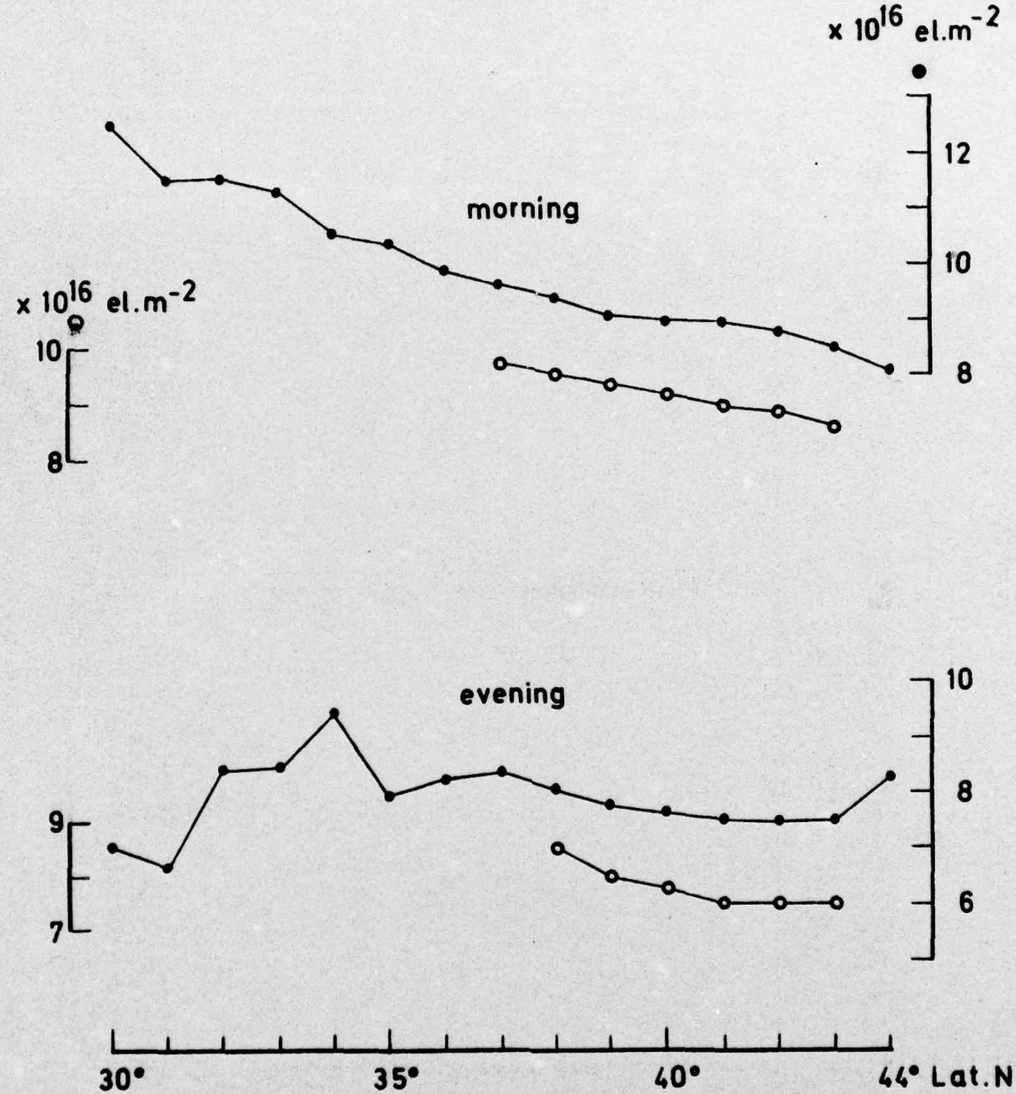

Fig. 6.- Latitudinal variation of TEC

are within the limits of a good statiscal significance. The difference between morning and evening errors can be due to the fact that, depending on the season, the ray path in the evening was some times in darkness, some times partially and some times totaly iluminated.

We can say that the latitudinal dependence of TEC is quite steady, changing a little from hour to hour in the morning and that it is stronger in the evening than in the morning hours.

NUMERICAL MODEL.

According with these results, a numerical model has been deduce that gives the TEC monthly values for the mentioned six half an hour periods as a function of latitude.

The model is valid for a period of low solar activity similar to the one analyzed in this report (annual mean Wolf numbers 15.5 for 1975 and 12.6 for 1976) and for a latitudinal range between 36º and 44ºN for the morning hours and between 38º and 43ºN in the evening.

A Fourier time serie fit to harmonic 4 was made separately to each latitude and hour for the 12 months interval, so that, for every hour and latitude we have

$$(TEC)_j = C_0 + \sum_{i=1}^{4} C_i \sin\left(i \frac{2\pi}{T} j + \varphi_i\right) \qquad j=1,12 \qquad (1)$$

where $(TEC)_j$ means the TEC monthly mean value of the j month. This gives nine coefficients for every latitude and hour ($C_0 \ldots C_4, \varphi_1 \ldots \varphi_4$).

For every hour, a third degree polynomial was fitted separately to each Fourier coefficient as a function of the latitude through the equation

$$(coef)_l = K_{l_0} + \sum_{m=1}^{3} K_{l_m} (lat. - 40°)^m \qquad l=0,8 \qquad (2)$$

Table I.- K_{l_m} coefficients (units 10^{14} el.m^{-2})

m=	0	1	2	3	m=	0	1	2	3
9h					19'30h				
l=0	849.322	-18.155	-1.345	-0.474	l=0	778.167	-22.835	5.865	-1.476
1	156.345	2.371	-0.544	0.566	1	487.533	1.080	-5.317	0.877
2	100.859	-10.882	2.785	0.220	2	23.274	10.522	5.036	-2.944
3	42.761	-8.476	1.476	0.105	3	52.345	2.620	-1.391	0.230
4	10.402	1.025	0.493	0.011	4	65.096	-14.866	0.955	1.158
5	252.323	-3.264	-0.155	0.312	5	256.697	0.712	-0.243	-0.034
6	190.347	4.038	-1.052	-0.413	6	316.543	40.436	-9.384	-1.057
7	205.173	-3.284	0.068	0.268	7	81.977	-10.789	4.321	-0.439
8	285.402	22.290	-1.873	-2.222	8	180.681	-6.696	0.658	0.469
9'30h					20h				
l=0	908.502	-20.290	1.010	0.260	l=0	716.562	-24.057	7.027	-1.221
1	136.054	1.782	-1.970	-0.352	1	449.525	16.368	2.159	0.462
2	104.831	-5.957	2.155	0.033	2	23.102	1.143	0.652	-0.567
3	54.950	-9.006	1.989	0.282	3	54.338	-0.148	0.318	-0.526
4	14.991	-7.716	2.233	0.039	4	44.130	-1.855	0.116	-0.091
5	221.273	1.974	-0.694	-0.112	5	262.029	-1.381	0.005	0.050
6	210.522	-2.494	-0.417	-0.156	6	111.095	36.493	-13.067	3.293
7	241.449	-8.141	0.505	0.363	7	32.645	-16.960	4.299	0.419
8	306.829	0.350	-1.287	-0.265	8	186.411	-15.213	-7.800	3.365
10h					20'30h				
l=0	960.427	-12.493	1.101	-0.181	l=0	638.420	-8.276	5.703	-1.675
1	109.836	5.692	-2.293	-0.349	1	359.030	8.460	5.513	-1.601
2	134.948	-9.546	-0.293	1.265	2	48.119	-2.807	-6.915	1.767
3	43.108	4.264	0.361	-0.405	3	66.468	-1.038	-0.862	-0.210
4	55.452	5.228	-0.829	-0.915	4	52.611	3.059	-0.296	-0.371
5	238.837	-5.054	-0.865	-0.140	5	255.681	-0.163	-0.656	0.226
6	216.812	-4.501	-0.823	-0.109	6	91.972	8.652	-5.550	0.650
7	270.784	0.111	-0.342	-0.044	7	342.043	8.846	-11.031	4.302
8	15.220	9.540	2.729	-0.689	8	143.284	-0.327	-2.786	1.299

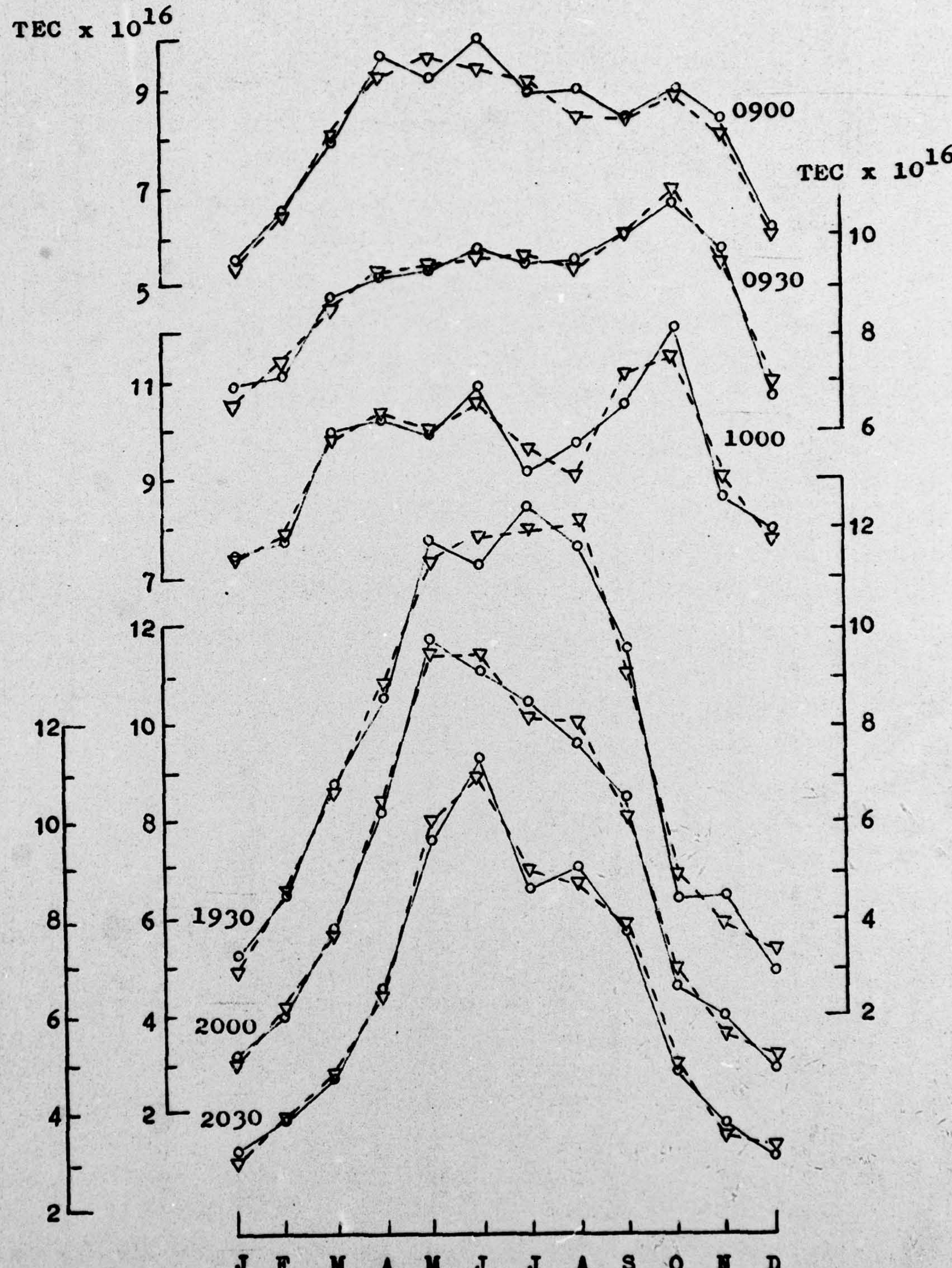

Fig. 7.- TEC annual variation at 41º N

o Data

▽ Fourier fitting

where

$$(\mathrm{coef})_l = \begin{cases} C_l & \text{for} \quad l=0,4 \\ \varphi_{l-4} & \text{"} \quad l=5,8 \end{cases}$$

Thus we have a set of 36 coefficients for every hour that will give the mean value of TEC at any given latitude (between the stated limits) at any month.

In table I we give the values of the Klm coefficients for the hours we have TEC data. With these values, the Fourier coefficients for any given latitude can be obtained through eq. 2, for any of the specified hours. With the Fourier coefficients the TEC for any month of the year can be deduced through eq. 1.

To give an idea of the accuracy of the fittings, we show in fig. 7 several examples of the TEC annual variation directly obtained from the data, and the Fourier fit. We give the curvas corresponding to the three morning and evening hours for the latitude of the Observatory (41ºN). As can be seen the fit is very good, although there is a small smoothing of several peaks due to the fact that we only took the first four harmonics in our analysis. Nevertheless, the highest r. m . s. TEC error that corresponds to the 1930LT curve is lower than $0.5 \cdot 10^{16}$ el m^{-2}.

The quality of the fit of the third degree polynomials can be deduced from table II, where the r.m.s. errors of the fitted Fourier coefficients are given. The mean value of the coefficients are also shown in the table to give an idea of the relative errors. All data are given in units 10^{14} el m^{-2}. As can be seen the errors are rather small and the higher one usually correspond to phases of harmonics of small amplitude, so that their influence in the TEC results are still less significant.

Finally, in table III we give the differences between the experimental TEC values and those obtained from the model. The monthly and latitudinal as well as the total, r. m. s. TEC error for every hour are also given. As in the pre-

	c_0	c_1	c_2	c_3	c_4	Φ_1	Φ_2	Φ_3	Φ_4
0900 LT									
Mean value	854.79	147.64	119.86	54.28	12.50	250.61	185.85	204.90	281.74
ε	3.17	1.56	3.32	4.80	1.04	0.96	1.61	1.17	36.17
0930 LT									
Mean value	922.01	127.14	119.40	68.13	30.81	217.36	210.72	245.39	301.69
ε	3.63	3.72	3.30	1.37	10.72	2.76	1.49	3.96	9.92
1000 LT									
Mean value	974.18	97.17	128.00	46.20	55.60	237.72	215.41	269.20	30.97
ε	2.02	4.68	6.88	3.19	5.12	2.29	1.78	5.92	12.06
1930 LT									
Mean value	778.68	475.18	31.24	50.28	65.90	256.13	302.29	88.29	181.52
ε	1.23	0.98	4.10	1.30	0.40	0.09	14.00	3.99	3.46
2000 LT									
Mean value	721.29	450.26	23.18	52.90	46.46	261.58	102.78	39.66	169.25
ε	1.32	1.54	1.97	2.20	1.53	0.07	2.07	1.91	1.48
2030 LT									
Mean value	644.81	373.50	32.77	62.27	51.53	254.54	81.65	330.89	140.15
ε	0.99	0.93	2.04	2.75	0.66	0.22	1.89	13.46	4.29

Table II.- Second degree polynomials errors (units 10^{14} el.m^{-2})

Lat. N	J	F	M	A	M	J	J	A	S	O	N	D	ε_λ
9h													
43°	1	9	-10	23	-20	18	-8	13	-1	16	-17	14	14.7
42°	-11	19	-15	23	-21	38	-32	26	-24	6	20	-2	23.0
41°	-3	11	-24	37	-35	45	-40	33	-13	-4	13	-10	27.8
40°	10	-3	-26	33	-67	44	-46	26	-7	-2	-1	-21	32.5
39°	28	-2	-16	41	-55	57	-45	29	-8	-2	8	-12	33.2
38°	2	25	-38	58	-50	72	-50	36	-8	-18	18	-4	40.1
37°	-39	39	-60	72	-89	72	-55	17	-2	-16	34	-11	52.0
36°	-27	59	-78	89	-86	71	-44	17	9	-12	-5	16	55.0
ε_m	22	30	43	56	63	59	45	27	12	12	18	13	35.7
9'30h													
43°	2	-16	6	2	-15	25	-22	16	-9	-9	7	-12	14.1
42°	55	-24	15	6	-13	16	-18	11	-2	2	21	-29	23.2
41°	47	-29	15	-1	-15	6	-17	17	0	2	29	-37	24.0
40°	29	-34	19	-13	-9	31	-28	28	-17	-15	19	-32	25.2
39°	-1	-41	40	-17	-1	42	-46	31	-32	-8	3	-20	29.8
38°	32	-49	43	-18	-5	26	-46	54	-51	44	-16	-12	38.3
37°	102	-55	43	-17	-13	25	-58	77	-65	69	-25	-16	56.8
36°	22	-59	53	-31	-3	48	-69	75	-68	26	2	-28	49.0
ε_m	51	44	36	17	11	32	45	49	43	33	19	27	33.9
10h													
43°	-3	-12	7	11	-32	52	-69	79	-89	83	-39	23	53.9
42°	5	-15	22	-13	-5	44	-71	77	-67	35	-57	25	46.0
41°	-2	-7	21	-23	-10	37	-58	83	-64	43	-46	20	43.8
40°	-8	-10	1	13	-20	32	-36	56	-65	75	-16	8	38.6
39°	12	-13	-8	24	-20	19	-38	28	-46	52	4	-9	28.3
38°	32	-10	3	7	-22	23	-50	31	-17	-28	17	-25	26.4
37°	22	-21	18	-12	-19	58	-25	31	16	-43	21	-24	29.8
36°	23	-26	14	-1	1	-19	9	-15	-4	13	8	-21	15.8
ε_m	18	16	15	16	20	41	52	60	58	55	34	22	35.8

Table III.- Differences between data and model ($\times 10^{14}$ el.m^{-2})

19'30h

Lat. N	J	F	M	A	M	J	J	A	S	O	N	D	ε_λ
43°	54	-35	24	-15	9	-10	22	-34	51	-61	61	-59	43.0
42°	25	-35	26	-17	28	-45	42	-52	53	-49	58	-53	44.0
41°	39	-16	25	-29	37	-49	55	-55	59	-54	48	-44	46.1
40°	42	-12	-4	-13	16	-21	43	-41	52	-65	46	-38	38.9
39°	13	3	-34	37	-28	14	25	-62	64	-78	82	-47	49.7
38°	37	14	-46	71	-62	25	14	-62	110	-122	112	-87	76.3
ε_m	41	25	32	40	38	34	40	57	75	83	78	62	49.4

20h

Lat. N	J	F	M	A	M	J	J	A	S	O	N	D	ε_λ
43°	23	-24	25	-24	24	-20	16	-16	15	-12	16	-18	20.7
42°	11	-14	21	-23	22	-32	34	-27	28	-34	23	-22	26.4
41°	21	-16	9	-17	24	-24	35	-44	40	-32	29	-19	28.9
40°	29	-24	27	-19	21	-19	20	-30	38	-31	29	-22	27.5
39°	33	-38	36	-37	32	-37	42	-45	45	-51	49	-51	43.5
38°	64	-55	51	-49	55	-62	69	-75	82	-80	76	-68	69.3
ε_m	38	35	34	33	35	39	44	48	50	49	46	42	38.2

20'30h

Lat. N	J	F	M	A	M	J	J	A	S	O	N	D	ε_λ
43°	3	10	-17	17	-22	26	-16	4	4	-2	6	-8	14.2
42°	22	-13	-12	38	-31	20	-35	30	-8	-26	23	-13	25.4
41°	20	-6	-3	19	-42	49	-33	30	-11	3	19	-29	37.4
40°	27	-4	6	-3	-39	62	-31	4	-16	11	22	-39	29.2
39°	41	-38	-6	39	-25	23	-57	53	-6	-30	26	-28	36.0
38°	125	-49	-110	84	26	31	-147	72	86	-58	-54	-3	84.9
ε_m	61	29	50	46	34	42	75	44	40	32	31	26	41.2

Table III.- Differences between data and model ($\times 10^{14}$ el.m^{-2})

vious table the units are 10^{14} el m^{-2}. As can be seen the differences and errors are very small. Only 7 from the 504 values reach 10^{16} el m^{-2} and the monthly r. m. s. errors remain always below 0.5 10^{16} el m^{-2}. We can say that, in general, the errors of the model are within the errors of the experimental data.

With TEC data obtained from the signal of the BE-B satellite recorded at the University of Athens, Klobuchar (1973) deduced a numerical model for the mediterranean area. The model gives the diurnal variation of TEC for the four seasons of the year and for different solar activity levels. They go from a solar flux in 10.7 cm of 90 in spring to 130 in winter (all in units of 10^{-22} w m^{-2} Hz^{-1}) the r.m.s. errors for the different seasons, that correspond to our monthly r.m.s. errors, oscilate between 0.9 10^{16} el m^{-2} and 1.6 10^{16} el m^{-2}. The results of this model cannot be properly compared with ours because they belong to periods of higher solar activity and are grouped in a very different way. Nevertheless, an idea of the compatibility of the results of both models can be deduced. The nearest conditions to our model correspond to Klobuchar's Season I (Spring (march 21), mean 10.7 cm flux equal to 90 10^{-22} w m^{-2} Hz^{-1}). For this period the TEC values obtained from his model between 0900 and 1000LT are slightly higher than our values, as expected. Only at 1000LT between 36º and 37ºN, the values of our model are a little higher than Klobuchar's. On the evening, our values are clearly higher than those of Klobuchar. These results, even the last one that seems a little suprising at first sight, are in agreement with the results obtained by Galdón(1968). He finds that for 9 and 10 hours, the TEC values on March-April 1966 are higher than on March-April 1965 when the solar activity was lower. At 20 hours on the contrary, the values of 1966 are lower than those of 1965. Also it must be noted that at 11 hours, the values of 1965 are lower than those of 1966. These data correspond to 41ºN. It is possi-

ble that the variation of TEC follows the same pattern at lower latitudes, but the inversion of differences in the morning hours occurs a little earlier. This would explain the differences of the two models between 36º and 37º at 1000LT.

In fig. 8, the isocontours of constant TEC obtained from the experimental data and from the model are shown. As can be seen, the model fit is quite good. Only the regions of greater gradients of TEC, appear slightly smoothed in the model. As we said already, this is due in part to the limitation of number of Fourier harmonics but also to the fact that a forth degree polynomial would fit better than a third one some of the Fourier coefficients.Thus, for instance, the isoline of 10×10^{16} el m^{-2} in the 0900LT map, that covers the months of March to June, appears smoothed in the model. Also, the two maxima of April and June, as well as the May minimum at low latitudes, do not appear in the model. However, all the differences are small and,as we said already, remain within the error of the experimental data.

Finally, we must point out the limitations of the model: first of all it gives only mean values of TEC, is valid for low solar activity conditions (mean Wolf number about 14) and for the stated hours and range of latitude. Besides,the model has been deduced for the Iberian peninsula and west Mediterranean zone. The fitness to other regions of different longitude, is limited by the longitudinal asymmetry of the ionosphere.

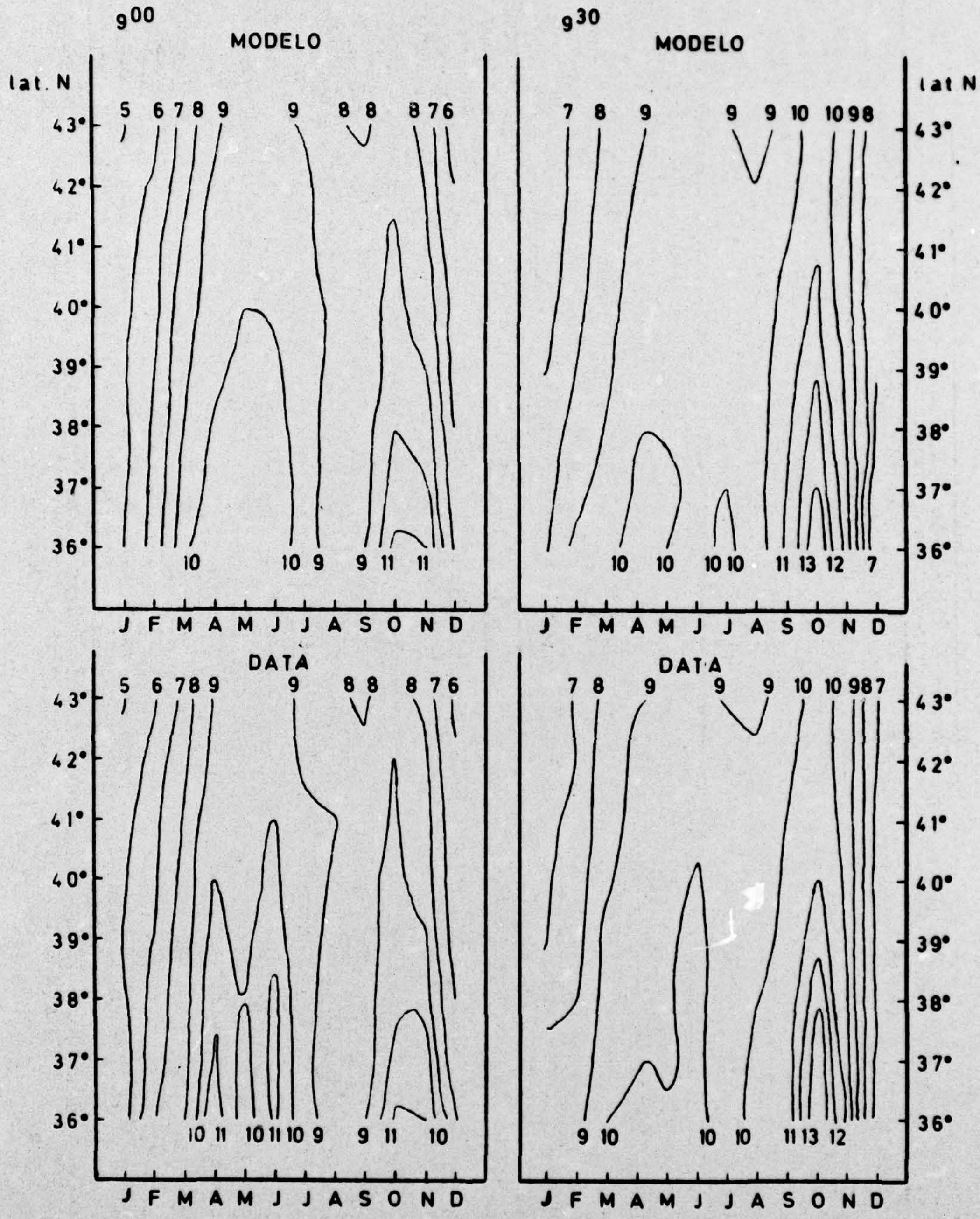

Fig. 8.- TEC isocontours (units 10^{16} el.m^{-2})

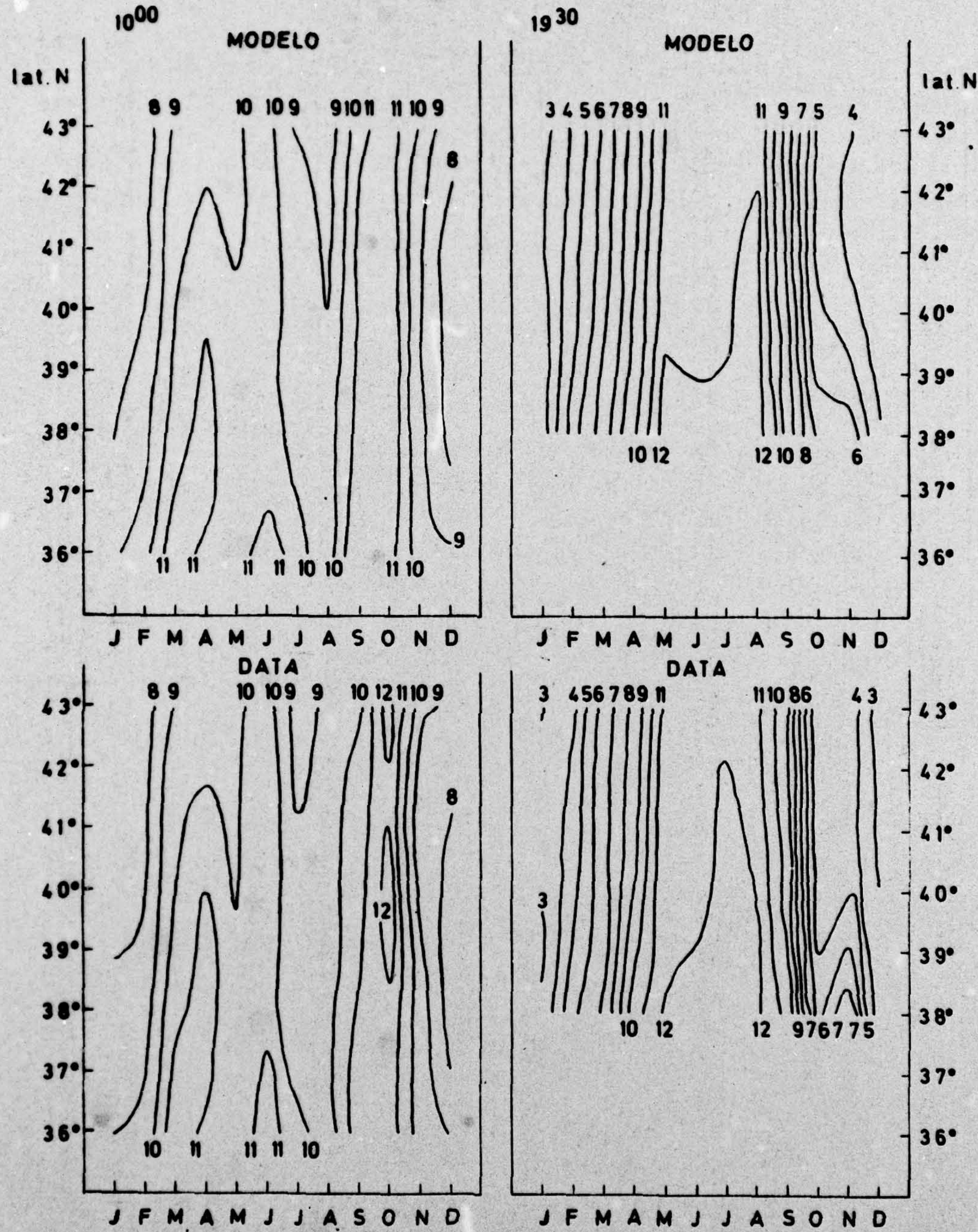

Fig. 8.- TEC isocontours (units 10^{16} el.m^{-2})

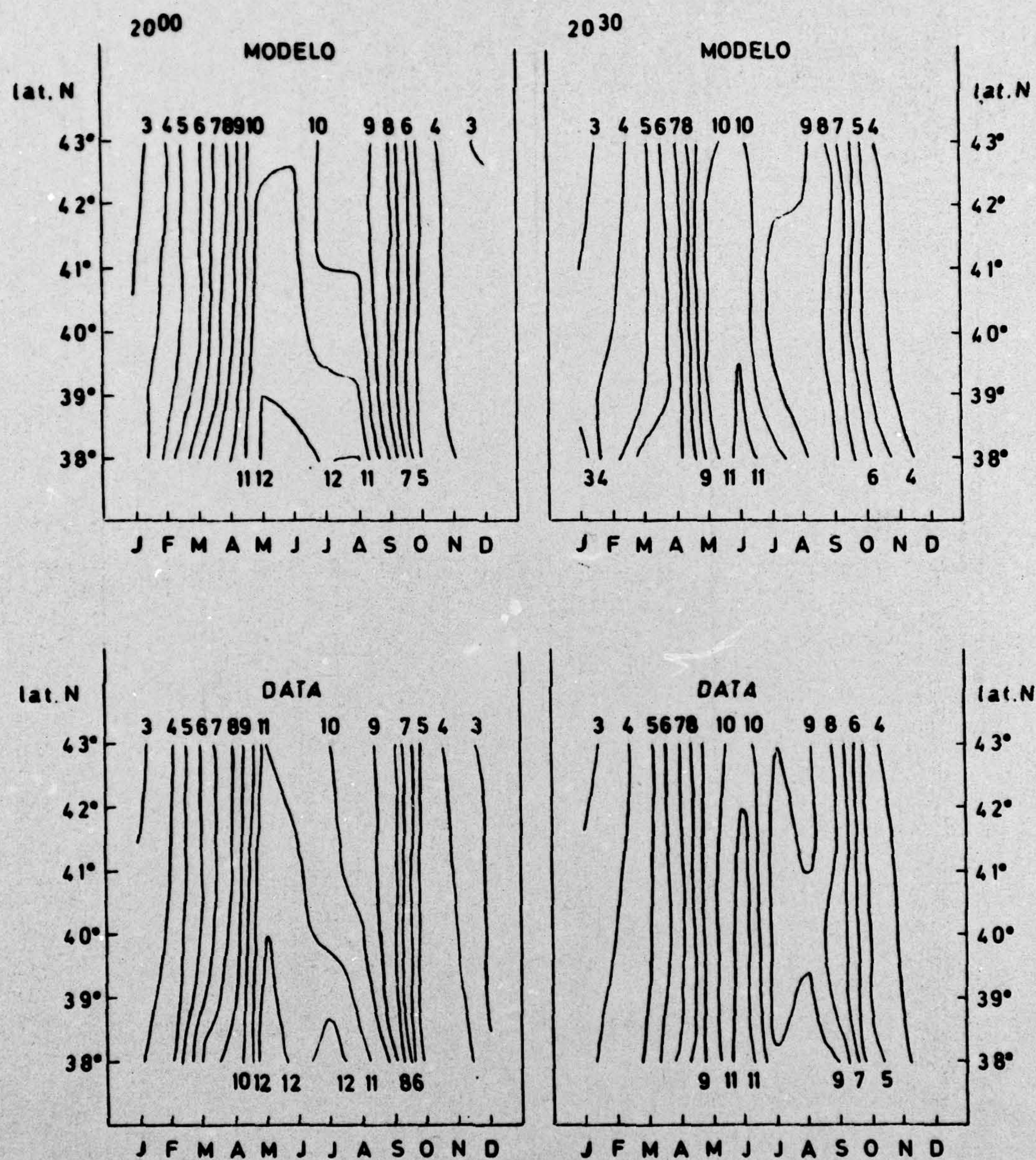

Fig. 8.- TEC isocontours (units 10^{16} el.m^{-2})

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